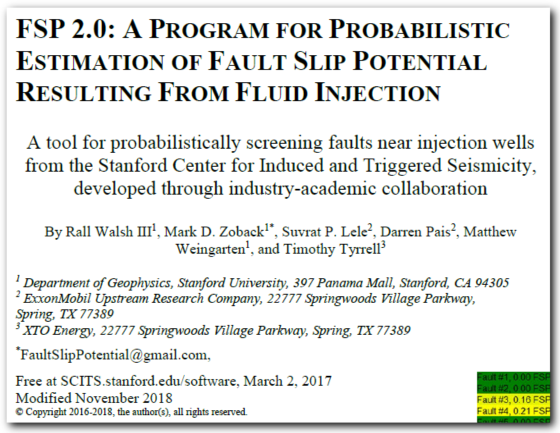
## Fault Slip Analysis

{Note: For Item 8 on Injection Permit work tracker}

A probabilistic fault-slip potential analysis was performed on the faults that create the boundary of the proposed Fault Block E and the results indicated that no slip will occur, based on the maximum proposed reservoir pressure increase of 616 psi as proposed when calculating injection capacity. Details of the analysis are discussed below.

A fault-slip-analysis was performed on the faults that create the boundary of Fault Block E using a software program named **FSP2.0: A Program for Probabilistic Estimation of Fault Slip Potential Resulting From Fluid Injection (FSP)**. See **Exhibit ???-???** for more information on this package.



**FSP 2.0: A PROGRAM FOR PROBABILISTIC ESTIMATION OF FAULT SLIP POTENTIAL RESULTING FROM FLUID INJECTION**

A tool for probabilistically screening faults near injection wells from the Stanford Center for Induced and Triggered Seismicity, developed through industry-academic collaboration

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Fault #1, 0.00 FSP
Fault #2, 0.00 FSP
Fault #3, 0.18 FSP
Fault #4, 0.21 FSP

*Exhibit ???-??? – FSP2.0 Analysis Software Information*

The method used for this analysis is to calculate the Mohr-Coulomb slip criteria based on the reservoir pressure increase as a result of fluid injection. Each fault location, well location, injection rates, hydrologic parameters, and mechanical stress state parameters are input to create the model and to perform the analysis. The program assumes the faults are not sealing and are exposed to the pressure field in which they are located. The pressure field in the matrix can also be entered manually, rather than using the pressure field estimated from the program's radial flow assumption. The probabilistic estimation portion of this approach is performed by Monte Carlo simulations of multiple combinations of variations of the expected input geomechanical and hydrologic data.

To generate the model 2-D matrix, the isopach map of Fault Block E (see **Exhibit ???-???)** was utilized to create a two-dimensional grid of the fault placement and the well placement relative to the faults. These faults were approximated using 4 linear faults. The fault dip for each fault is 45 degrees. **Exhibit ???-???** shows the output from FSP of the resultant fault orientation utilized for the analysis. **Exhibit ???-???** is a table showing the resultant fault data required by the program. Note that the X and Y values are the midpoints of the faults.

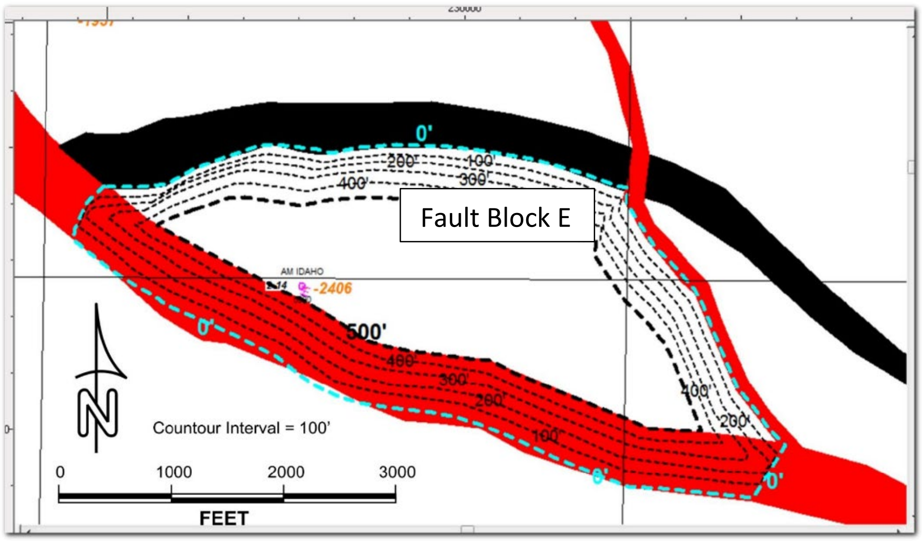



*Exhibit ???-??? - Fault Block E Gross Sand Isopach*

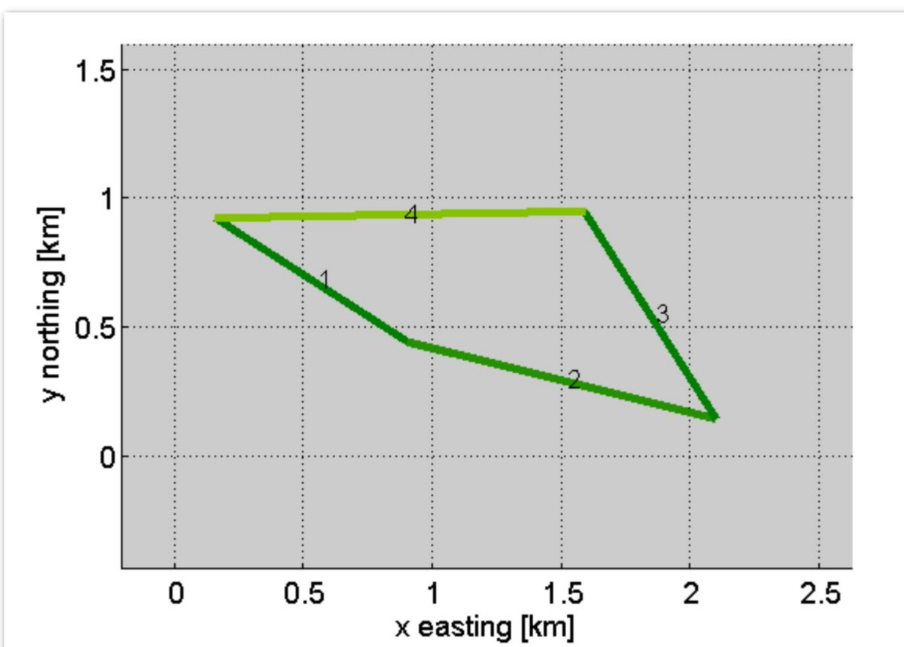



*Exhibit ???-??? – Fault Block E Boundary Faults Visualization in FSP Model*

| | |
|---|---|
| Number of faults (max 500) | 4 |
| Friction Coefficient mu | 0.6 |

○ Random Faults
◉ Enter Faults

| | X [East km] | Y [North km] | Strike [Deg] | Dip [Deg] | Length [km] |
|---|---|---|---|---|---|
| 1 | 0.5270 | 0.6815 | 122.8000 | 45 | 0.8873 |
| 2 | 1.4943 | 0.2926 | 104.0030 | 45 | 1.2251 |
| 3 | 1.8384 | 0.5462 | 147.5950 | 45 | 0.9519 |
| 4 | 0.8687 | 0.9351 | 88.9584 | 45 | 1.4296 |

*Exhibit ???-??? – Table of Fault Data for FSP*

Stress data input for the fracture slip potential analysis is shown in the table below.

Stress Data

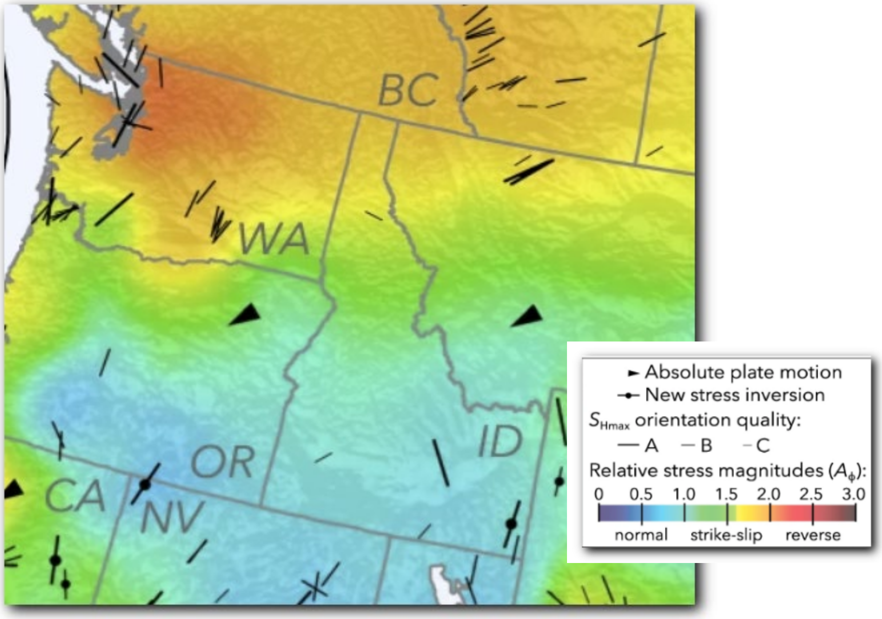
○ Specify All Three Stress Gradients [psi/ft]
◉ Use A-Phi Model

| | |
|---|---|
| Vertical Stress Gradient [psi/ft] | 1 |
| A-Phi Parameter | 0.75 |
| ☑ Min Horiz Stress Grad Available [psi/ft] | 0.77688 |
| Max Hor Stress Direction [deg N CW] | 45 |
| Initial Res. Pressure Gradient [psi/ft] | 0.43 |
| Reference Depth for Calculations [ft] | 5150 |

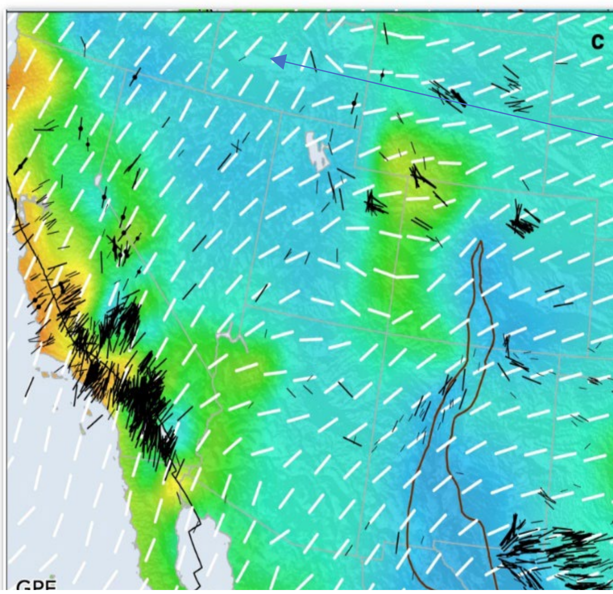
*Exhibit ???-??? – Stress Data Inputs for FSP Analysis*

A vertical stress gradient of 1 psi/ft is assumed and the A-phi Parameter of 0.75 was sourced from a recent publication that addresses the variation of the crustal stress field throughout North America. See **Exhibit ???-???** Additional detail from this publication is also shown below in **Exhibit ???-???** that includes the southern portion of Idaho. below. The horizontal principal stress direction and relative stress magnitudes utilized for this analysis were determined from this paper, along with data from the relatively close geothermal exploration MH-2 Borehole, since no other direct information was available from the wellbores in this immediate vicinity. The MH-2 borehole was drilled in 2011 as part of an effort to examine the potential for the presence of commercial geothermal energy resources in the Snake River Plain. Borehole imaging identified borehole breakouts that indicated a maximum horizontal stress direction of N47E +7°. This well is located at Mountain Home Airforce Base, approximately 80 miles southeast of the subject Fault Block E. Shown below in **Exhibit ???-???** is a locator map for the MH-2 well, along with the article citation and a link to the article.

**Exhibit ???-???** is from a 2020 publication in Nature Communications: (Lund Snee, J., Zoback, M.D. Multiscale variations of the crustal stress field throughout North America. *Nat Commun* **11,** 1951 (2020). https://doi.org/10.1038/s41467-020-15841-5.




State of stress in North America




Southern portion of Idaho.

https://www.nature.com/articles/s41467-020-15841-5/figures/4

**a**–**c** Modeled $S_{Hmax}$ orientations by Ghosh et al.[4] that account for **a** only gravitational potential energy (GPE), **b** basal tractions (BT) from modeled mantle flow, and **c** a combination of GPE and BT. **d** A model of $S_{Hmax}$ orientations by Flesch et al.[47] that considered a smaller study area incorporated only GPE and plate boundary stresses (PBS), using simpler inputs and a smaller study area.

RESEARCH ARTICLE | JUNE 01, 2017

**Geology and in situ stress of the MH-2 borehole, Idaho, USA: Insights into western Snake River Plain structure from geothermal exploration drilling**

J.A. Kessler; K.K. Bradbury; J.P. Evans; M.A. Pulsipher; D.R. Schmitt; J.W. Shervais; F.E. Rowe; J. Varriale

Lithosphere (2017) 9 (3): 476–498.

https://doi.org/10.1130/L609.1 **Article history**

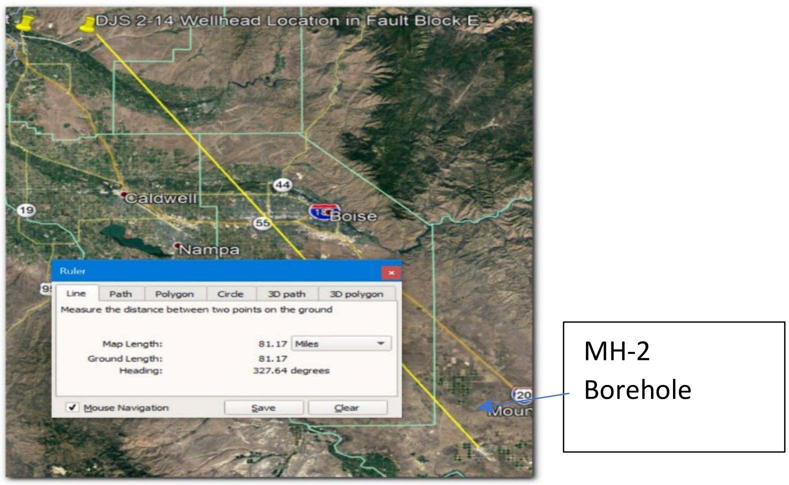



*Exhibit ???-??? – MH-2 Borehole location, relative to Fault Block E, Idaho, USA*

The minimum horizontal stress magnitude used in the analysis was estimated using the Zamora 1989 method. Shown below in **Exhibit ???-???** is the results from MI Swaco/Schlumberger's Mudware Program. The resultant minimum horizontal stress or fracture gradient is 14.94 lb/gallon. This equates to 0.77688 psi/ft (14.94 lb/gal * 0.052 (gal*psi)/(ft*lb) = 0.77688 psi/ft). Note that this value is higher than the conservative 12.0 lb/gal value used in the injection capacity calculation as the upper limiting value

MI SWACO
A Schlumberger Company

Fracture Gradient

**Data**

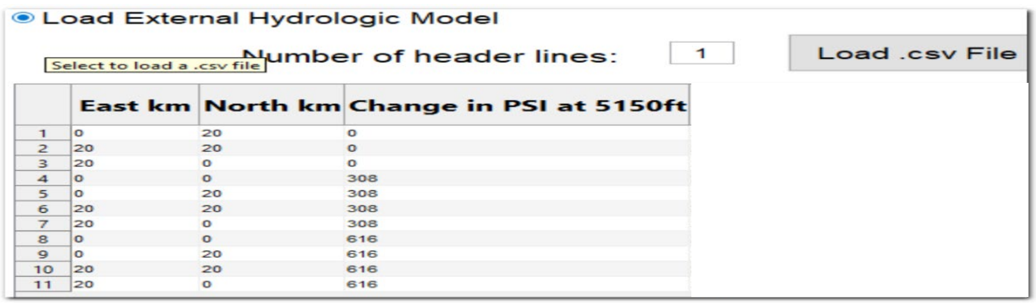
| | |
|---|---|
| True Vertical Depth [ft] | 5150 |
| Overburden Code (0-14.0) | 5 |
| Matrix Stress Code (0.2-1.0) | 1 |
| Pore Pressure [lb/gal] | 8.34 |
| Water Depth (Offshore) [ft] | 0 |
| Air Gap [ft] | 0 |

**Results**

| | | |
|---|---|---|
| Fracture Gradient | 14.94 | lb/gal |

*Exhibit ???-??? – Minimum Horizontal Stress / Fracture Gradient* for actual operational limits of injection, and indicates that the proposed injection capacity limitations are very conservative.

The FSP program allows for the calculation of pressure increases based on a radial flow model in a uniform infinite layer. Even though Fault Block E is bounded by faults which seal, the FSP analysis assumes that the faults communicate and there are no boundaries. Using a height of 400’ and a permeability of 300 md generated a negligible pressure response in the modeled pressure increases over the lifetime of injecting water. To simulate the pressure increase created by this confined reservoir, pressures were entered to simulate the expected pressure increase. Two pressure increases were input for modeling purposes 308 psi and 616 psi. The pressure was set to be uniform over the entire area. **Exhibit ???-???** shows the entered pressure profiles.


Load External Hydrologic Model

Select to load a .csv file

Number of header lines: 1

Load .csv File

| | East km | North km | Change in PSI at 5150ft |
|---|---|---|---|
| 1 | 0 | 20 | 0 |
| 2 | 20 | 20 | 0 |
| 3 | 20 | 0 | 0 |
| 4 | 0 | 0 | 308 |
| 5 | 0 | 20 | 308 |
| 6 | 20 | 20 | 308 |
| 7 | 20 | 0 | 308 |
| 8 | 0 | 0 | 616 |
| 9 | 0 | 20 | 616 |
| 10 | 20 | 20 | 616 |
| 11 | 20 | 0 | 616 |

*Exhibit ???-??? Hydrologic Model Pressure Input Data Table*

The results of the base geomechanical FSP analysis is shown below in **Exhibit ???-???** with a presentation that shows the faults with the pore pressure to slip, along with a Mohr Circle and a stereonet with the fault normals. The pore pressures to slip range from 1774 – 2430 psi.

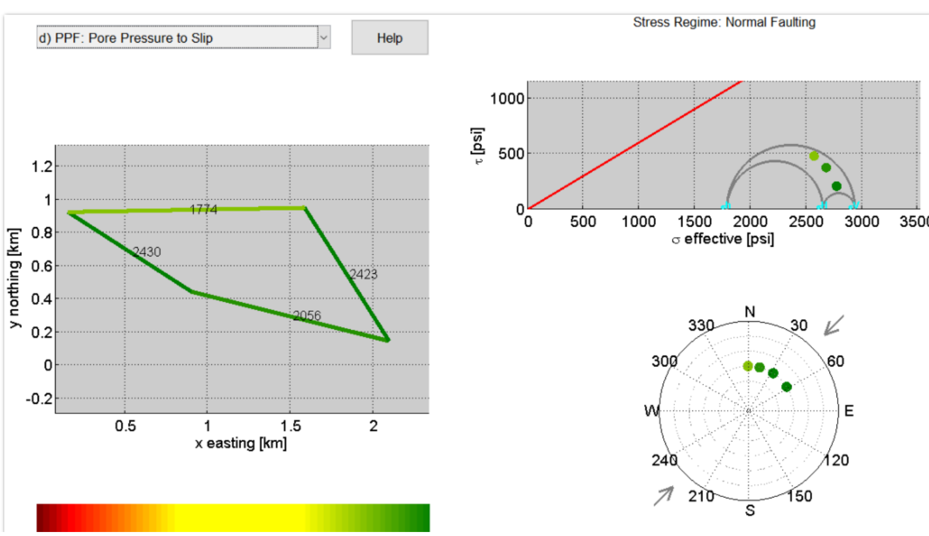



*Exhibit ???-??? Base Case Analysis Results*

A probabilistic Monte Carlo analysis was also performed, allowing for variation in the geomechanical stress model parameters. **Exhibit ???-???** shows the selections made for this model. These variations are expected to encompass the range of actual values that exist. The largest variations were assumed for maximum horizontal stress direction, fracture dip angles, and for the minimum horizontal gradient.

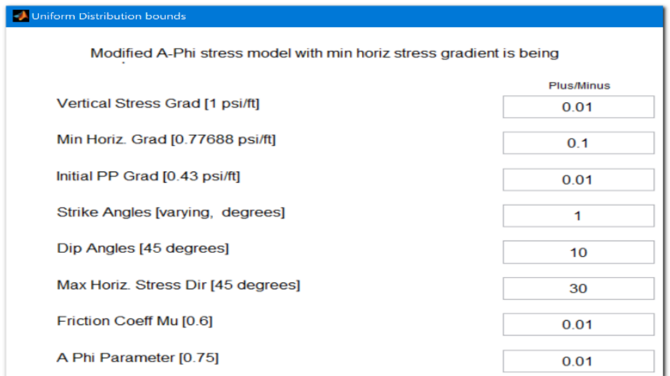



*Exhibit ???-??? Parameter variation selections for probabilistic Monte Carlo analysis.*

Shown below in **Exhibits ???-??? through ???-???** are displays of the probability of fault slip, along with the variability in inputs and the sensitivity analysis. The first exhibit shows all faults while the remainder 4 exhibits show individual faults with their sensitivity analysis.

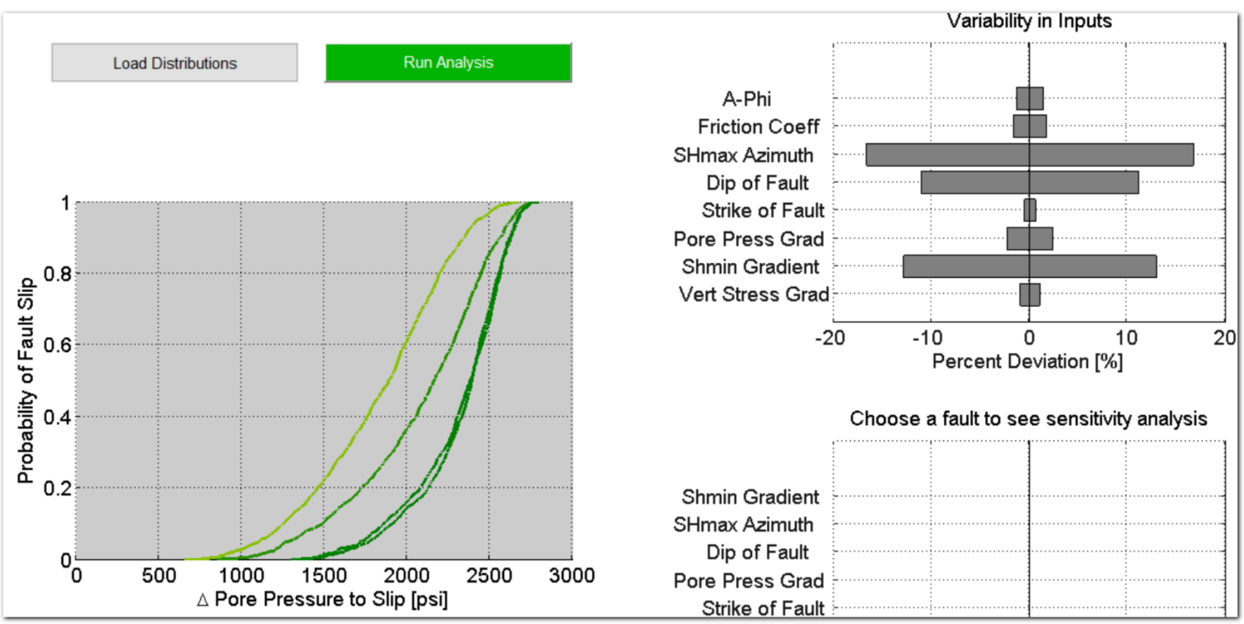



*Exhibit ???-??? Summary plot of all faults showing Probability of Fault Slip versus DPore Pressure to Slip*

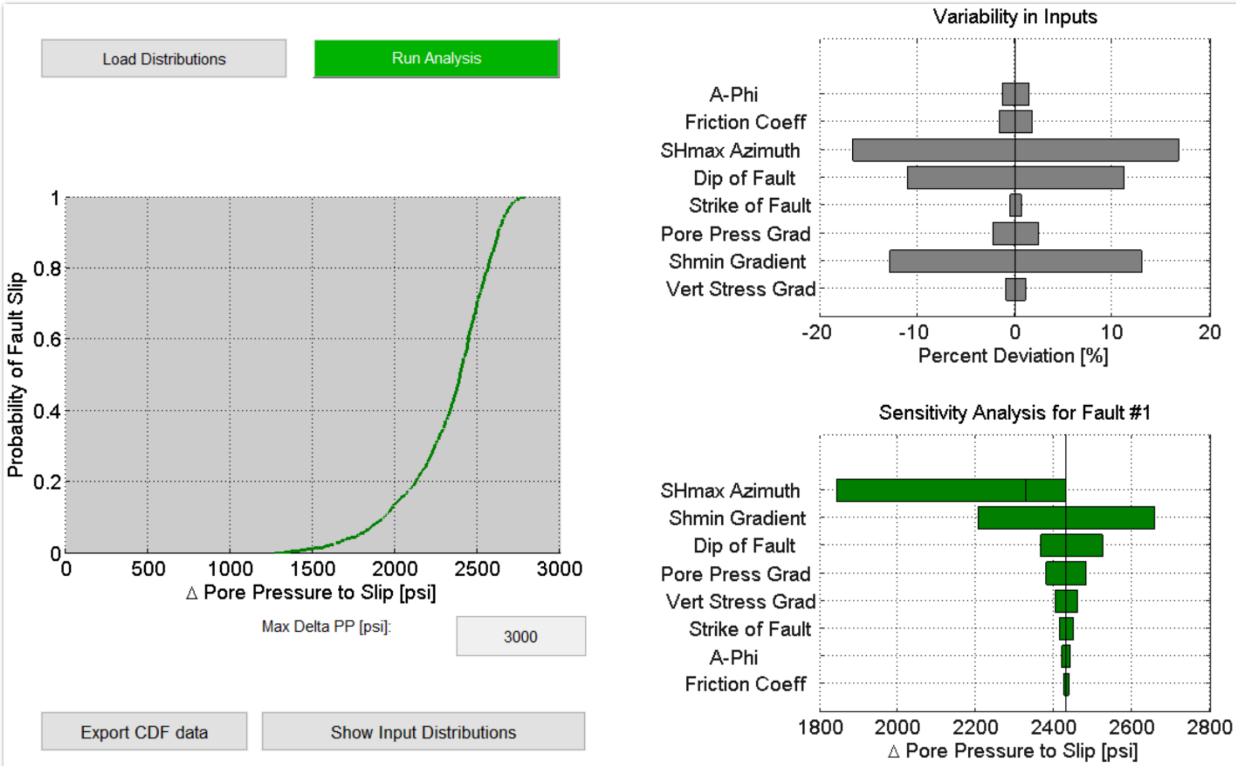



*Exhibit ???-???  Fault #1 Probabilistic Fault Slip Analysis*

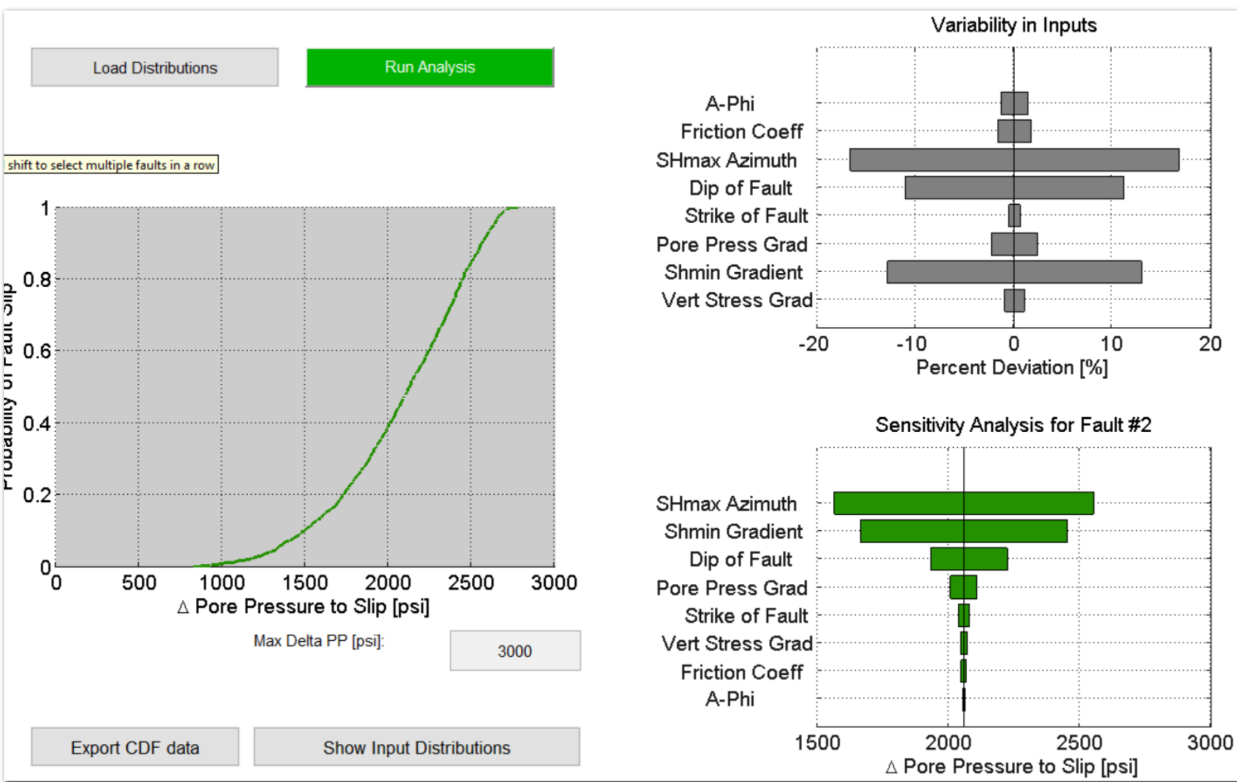



*Exhibit ???-???  Fault #2 Probabilistic Fault Slip Analysis*

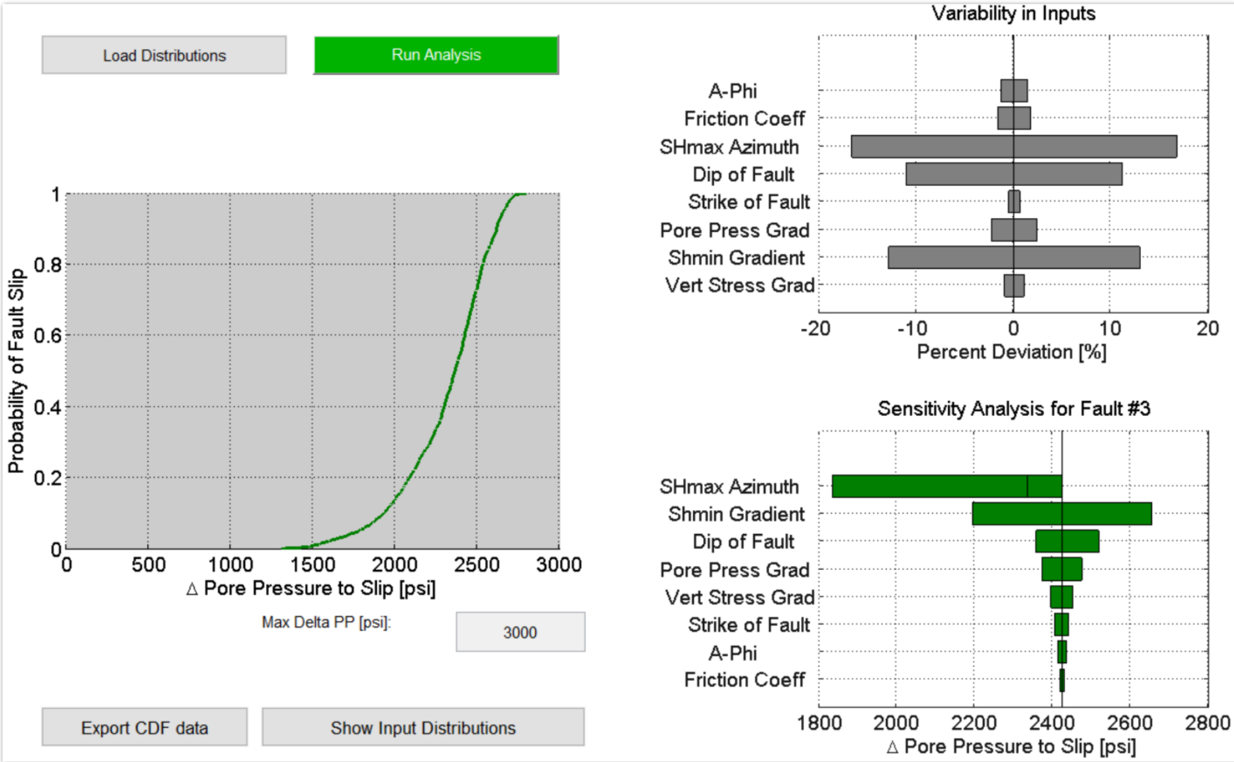



*Exhibit ???-???  Fault #3 Probabilistic Fault Slip Analysis*

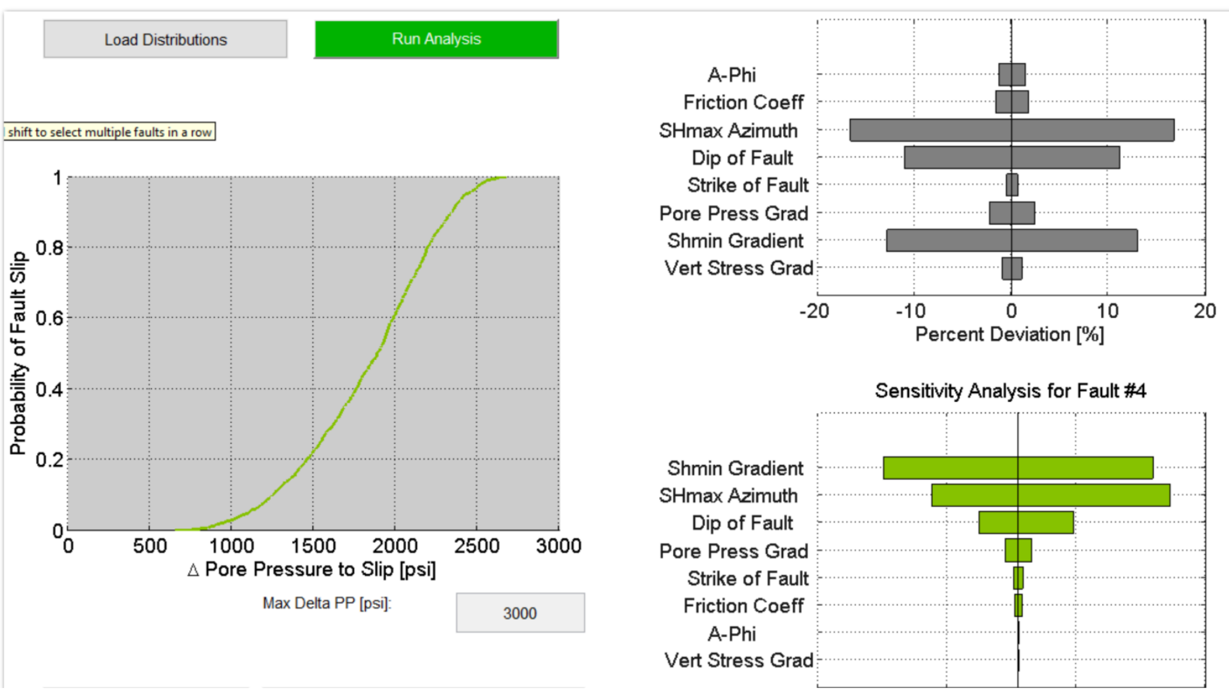



*Exhibit ???-???  Fault #4 Probabilistic Fault Slip Analysis*

Below is an exhibit that illustrates the pressure field that was used for the highest pressure increase. A uniform 616 psi is shown across the entire grid. The DJS 2-14 Well is shown by the numeral 1 in the lower left-hand side of the plot.